**Chapter 22 Section 2 Sun Earth Moon System**

**Key Concepts**

* [In what ways does Earth move?](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk622.3'))
* [What causes the phases of the moon?](javascript:openCrossRef('../ch22/ch22_s2_2.html%23lnk626.5'))
* [Why are eclipses relatively rare events?](javascript:openCrossRef('../ch22/ch22_s2_3.html%23lnk628.3'))

**Vocabulary**

* [rotation](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk622.3'))
* [apogee](javascript:openCrossRef('../ch22/ch22_s2_2.html%23lnk626.2'))
* [phases of the moon](javascript:openCrossRef('../ch22/ch22_s2_2.html%23lnk626.4'))
* [solar eclipse](javascript:openCrossRef('../ch22/ch22_s2_3.html%23lnk628.2'))
* [lunar eclipse](javascript:openCrossRef('../ch22/ch22_s2_3.html%23lnk628.2'))
* [revolution](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk622.3'))
* [precession](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk622.3'))
* [perihelion](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk624.1'))
* [aphelion](javascript:openCrossRef('../ch22/ch22_s2_1.html%23lnk624.1'))
* [perigee](javascript:openCrossRef('../ch22/ch22_s2_2.html%23lnk626.2'))

If you gaze away from the city lights on a clear night, it will seem that the stars produce a spherical shell surrounding Earth. This impression seems so real that it is easy to understand why many early Greeks regarded the stars as being fixed to a solid, celestial sphere. People have always been fascinated by the changing positions of the sun and moon in the sky. Prehistoric people, for example, built observatories. The structure known as Stonehenge, shown in Figure 11, was probably an attempt at better solar predictions. At the beginning of summer in the Northern Hemisphere (the summer solstice on June 21 or 22), the rising sun comes up directly above the heel stone of Stonehenge. Besides keeping this calendar, Stonehenge may also have provided a method of determining eclipses. In this section, you’ll learn more about the movements of bodies in space that cause events such as eclipses.

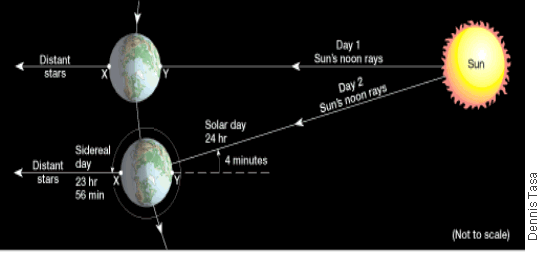
**Figure 11** *On the summer solstice, the sun can be observed rising above the heel stone of Stonehenge, an ancient observatory in England.*

**Motions of Earth**

**The two main motions of Earth are rotation and revolution.** [**Rotation**](javascript:openGlossaryWnd('e_ga_06_rotation')) is the turning, or spinning, of a body on its axis. [**Revolution**](javascript:openGlossaryWnd('e_ga_06_revolution')) is the motion of a body, such as a planet or moon, along a path around some point in space. For example, Earth revolves around the sun, and the moon revolves around Earth. Earth also has another very slow motion known as [**precession**](javascript:openGlossaryWnd('e_ga_06_precession')), which is the slight movement, over a period of 26,000 years, of Earth’s axis.

**Rotation**

The main results of Earth’s rotation are day and night. Earth’s rotation has become a standard method of measuring time because it is so dependable and easy to use. Each rotation equals about 24 hours. You may be surprised to learn that we can measure Earth’s rotation in two ways, making two kinds of days. Most familiar is the mean solar day, the time interval from one noon to the next, which averages about 24 hours. Noon is when the sun has reached its zenith, or highest point in the sky.

The sidereal day, on the other hand, is the time it takes for Earth to make one complete rotation (360 degrees) with respect to a star other than our sun. The sidereal day is measured by the time required for a star to reappear at the identical position in the sky where it was observed the day before. The sidereal day has a period of 23 hours, 56 minutes, and 4 seconds (measured in solar time), which is almost 4 minutes shorter than the mean solar day. This difference results because the direction to distant stars barely changes because of Earth’s slow revolution along its orbit. The direction to the sun, on the other hand, changes by almost 1 degree each day. This difference is shown in Figure 12.

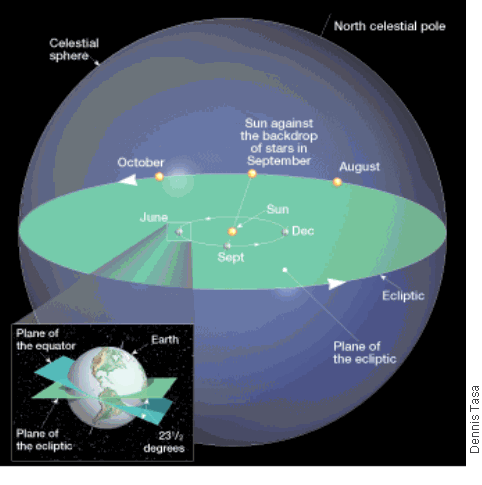
**Figure 12 Sidereal Day** *It takes Earth 23 hours and 56 minutes to make one rotation with respect to the stars (sidereal day). However, after Earth has completed one sidereal day, point Y has not yet returned to the “noon position” with respect to the sun. Earth has to rotate another 4 minutes to complete the solar day.*

Why do we use the mean solar day instead of the sidereal day as a measurement of our day? In sidereal time, “noon” occurs four minutes earlier each day. Therefore, after six months, “noon” occurs at “midnight.” Astronomers use sidereal time because the stars appear in the same position in the sky every 24 sidereal hours. Usually, an observatory will begin its sidereal day when the position of the spring equinox is directly overhead.

**Revolution**

Earth revolves around the sun in an elliptical orbit at an average speed of 107,000 kilometers per hour. Its average distance from the sun is 150 million kilometers. But because its orbit is an ellipse, Earth’s distance from the sun varies. At [**perihelion**](javascript:openGlossaryWnd('e_ga_06_perihelion')), Earth is closet to the sun—about 147 million kilometers away. Perihelion occurs about January 3 each year. At [**aphelion**](javascript:openGlossaryWnd('e_ga_06_aphelion')), Earth is farthest from the sun—about 152 million kilometers away. Aphelion occurs about July 4. So Earth is farthest from the sun in July and closest to the sun in January.

Because of Earth’s annual movement around the sun, each day the sun appears to be displaced among the constellations at a distance equal to about twice its width, or 1 degree. The apparent annual path of the sun against the backdrop of the celestial sphere is called the ecliptic, as shown in Figure 13. Generally, the planets and the moon travel in nearly the same plane as Earth. So their paths on the celestial sphere lie near the ecliptic.



**Figure 13 The Ecliptic** *Earth’s orbital motion causes the apparent position of the sun to shift about 1 degree each day on the celestial sphere.*

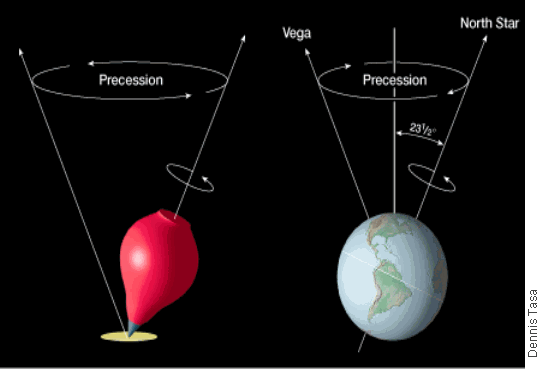
**Earth’s Axis and Seasons**

The imaginary plane that connects Earth’s orbit with the celestial sphere is called the plane of the ecliptic. From the reference plane, Earth’s axis of rotation is tilted about 23.5 degrees. Because of Earth’s tilt, the apparent path of the sun and the celestial equator intersect each other at an angle of 23.5 degrees. This angle is very important to Earth’s inhabitants. Because of the inclination of Earth’s axis to the plane of the ecliptic, Earth has its yearly cycle of seasons.

When the apparent position of the sun is plotted on the celestial sphere over a period of a year’s time, its path intersects the celestial equator at two points. From a Northern Hemisphere point of view, these intersections are called the spring equinox (March 20 or 21) and autumn equinox (September 22 or 23). On June 21 or 22, the date of the summer solstice, the sun appears 23.5 degrees north of the celestial equator. Six months later, on December 21–22, the date of the winter solstice, the sun appears 23.5 degrees south of the celestial equator.

**Precession**

A third and very slow movement of Earth is called precession. Earth’s axis maintains approximately the same angle of tilt. But the direction in which the axis points continually changes. As a result, the axis traces a circle on the sky. This movement is very similar to the wobble of a spinning top, as shown in Figure 14A. At the present time, the axis points toward the bright star Polaris. In the year 14,000, it will point toward the bright star Vega, which will then become the North Star, as shown in Figure 14B. The period of precession is 26,000 years. By the year 28,000, Polaris will once again be the North Star.

**Figure 14 Precession A** Precession is similar to a spinning top. It causes the North Pole to point at different parts of the sky during a 26,000-year cycle. **B** Today, the North Pole points to Polaris. **Interpreting Illustrations** What star will the North Pole point to in 13,000 years?

Precession has only a minor effect on the seasons, because the angle of tilt changes only slightly. It does, however, cause the positions of the seasons (equinox and solstice) to move slightly each year among the stars.

**Earth-Sun Motion**

In addition to its own movements, Earth accompanies the sun as the entire solar system speeds in the direction of the bright star Vega at 20 kilometers per second. Also, the sun, like other nearby stars, revolves around the galaxy. This trip takes 230 million years to traverse at speeds approaching 250 kilometers per second. The galaxies themselves are also in motion. Earth is presently approaching one of its nearest galactic neighbors, the Great Galaxy in Andromeda. The motions of Earth are many and complex, and its speed in space is very great.

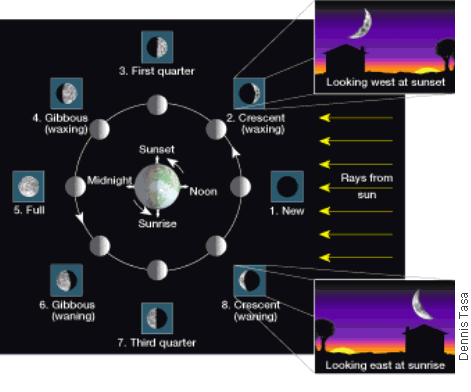
**Motions of the Earth-Moon System**

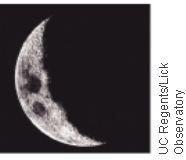
Earth has one natural satellite, the moon. In addition to accompanying Earth in its annual trip around the sun, our moon orbits Earth within a period of about one month. When viewed from above the North Pole, the direction of this motion is counterclockwise. Because the moon’s orbit is elliptical, its distance to Earth varies by about 6 percent, averaging 384,401 kilometers. At a point known as [**perigee**](javascript:openGlossaryWnd('e_ga_06_perigee')), the moon is closest to Earth. At a point known as [**apogee**](javascript:openGlossaryWnd('e_ga_06_apogee')), the moon is farthest from Earth.

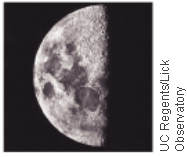
The motions of the Earth-moon system constantly change the relative positions of the sun, Earth, and moon. This results in changes in the appearance of the moon, as you’ll read about next.

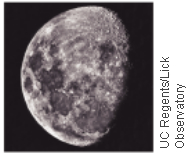
**Phases of the Moon**

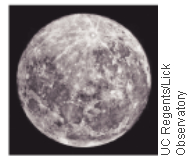
The first astronomical event to be understood was the regular cycle of the phases of the moon. On a monthly basis, we observe the [**phases of the moon**](javascript:openGlossaryWnd('e_ga_06_phasesthmoon')) as a change in the amount of the moon that appears lit. Look at the new moon shown in Figure 15A. About two days after the new moon, a thin sliver (crescent phase) appears low in the western sky just after sunset. During the following week, the lighted portion of the moon visible from Earth increases (waxing) to a half circle (first-quarter phase) and can be seen from about noon to midnight. In another week, the complete disk (full-moon phase) can be seen rising in the east as the sun is sinking in the west. During the next two weeks, the percentage of the moon that can be seen steadily declines (waning), until the moon disappears altogether (new-moon phase). The cycle soon begins again with the reappearance of the crescent moon.











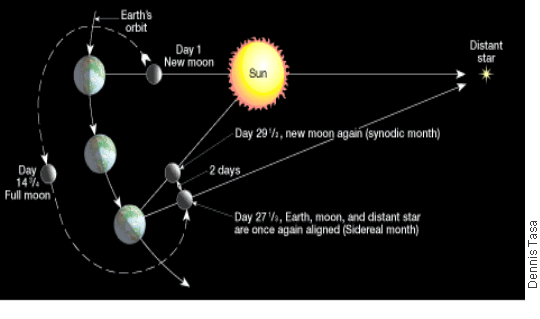
**Figure 15 Phases of the Moon *A*** *The outer figures show the phases as seen from Earth.* ***B*** *Compare these photographs with the diagram.*

**Lunar phases are a result of the motion of the moon and the sunlight that is reflected from its surface.** See Figure 15B. Half of the moon is illuminated at all times. But to an observer on Earth, the percentage of the bright side that is visible depends on the location of the moon with respect to the sun and Earth. When the moon lies between the sun and Earth, none of its bright side faces Earth.

When the moon lies on the side of Earth opposite the sun, all of its lighted side faces Earth. So we see the full moon. At all positions between the new moon and the full moon, a part of the moon’s lit side is visible from Earth.

**Lunar Motions**

The cycle of the moon through its phases requires 29 ½ days, a time span called the synodic month. This cycle was the basis for the first Roman calendar. However, this is the apparent period of the moon’s revolution around Earth and not the true period, which takes only 27 ⅓ days and is known as the sidereal month. The reason for the difference of nearly two days each cycle is shown in Figure 16. Note that as the moon orbits Earth, the Earth-moon system also moves in an orbit around the sun. Even after the moon has made a complete revolution around Earth, it has not yet reached its starting position, which was directly between the sun and Earth (new-moon phase). The additional motion to reach the starting point takes another two days.



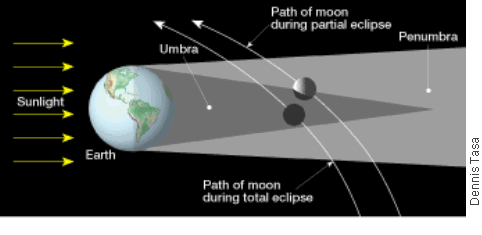
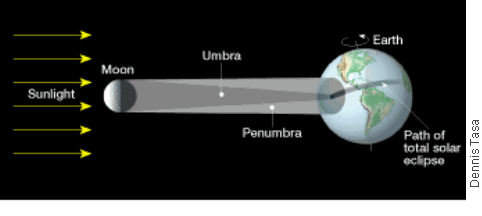
**Figure 16 Lunar Motion** *As the moon orbits Earth, the Earth-moon system also moves in orbit around the sun. Thus, even after the moon makes one revolution around Earth, it has not yet reached its starting point in relation to the stars.*

An interesting fact about the motions of the moon is that the moon’s period of rotation about its axis and its revolution around Earth are the same. They are both 27 ⅓ days. Because of this, the same side of the moon always faces Earth. All of the crewed Apollo missions took place on the side of the moon facing Earth. Only orbiting satellites and astronauts have seen the “back” side of the moon.

Because the moon rotates on its axis only once every 27 ⅓ days, any location on its surface experiences periods of daylight and darkness lasting about two weeks. This, along with the absence of an atmosphere, accounts for the high surface temperature of 127°C on the day side of the moon and the low surface temperature of −173°C on its night side.

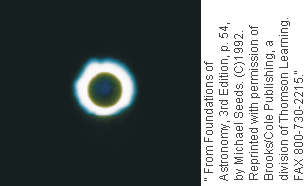
**Eclipses**

Along with understanding the moon’s phases, the early Greeks also realized that eclipses are simply shadow effects. When the moon moves in a line directly between Earth and the sun, it casts a dark shadow on Earth. This produces a [**solar eclipse**](javascript:openGlossaryWnd('e_ga_06_solareclipse')). This situation occurs during new-moon phases. The moon is eclipsed when it moves within Earth’s shadow, producing a [**lunar eclipse**](javascript:openGlossaryWnd('e_ga_06_lunareclipse')). This situation occurs during full-moon phases. Figure 17 illustrates solar and lunar eclipses.

**Figure 17 *A*** *Observers in the umbra see a total solar eclipse. Those in the penumbra see a partial eclipse. The path of the solar eclipse moves eastward across the globe. The figure shows a total solar eclipse.* ***B*** *During a total lunar eclipse, the moon’s orbit carries it into Earth’s umbra. During a partial eclipse, only a portion of the moon enters the umbra.*

Why doesn’t a solar eclipse occur with every new moon and a lunar eclipse with every full moon? They would if the orbit of the moon lay exactly along the plane of Earth’s orbit. However, the moon’s orbit is inclined about 5 degrees to the plane that contains Earth and the sun. During most new-moon phases, the shadow of the moon misses Earth (passes above or below). During most full-moon phases, the shadow of Earth misses the moon. **During a new-moon or full-moon phase, the moon’s orbit must cross the plane of the ecliptic for an eclipse to take place.** Because these conditions are normally met only twice a year, the usual number of eclipses is four. These occur as a set of one solar and one lunar eclipse, followed six months later with another set. Occasionally, the alignment can result in additional eclipses. However, the total number of eclipses in one year isn’t more than seven.

During a total lunar eclipse, Earth’s circular shadow can be seen moving slowly across the disk of the full moon. When totally eclipsed, the moon is completely within Earth’s shadow, but it is still visible as a coppery disk. This happens because Earth’s atmosphere bends and transmits some long-wavelength light (red) into its shadow. A total eclipse of the moon can last up to four hours and is visible to anyone on the side of Earth facing the moon.

During a total solar eclipse, the moon casts a circular shadow that is never wider than 275 kilometers, about the size of South Carolina. Anyone observing in this region will see the moon slowly block the sun from view and the sky darken. When the eclipse is almost complete, the temperature sharply drops a few degrees. The solar disk is completely blocked for seven minutes at the most. This happens because the moon’s shadow is so small. Then one edge reappears.

When the eclipse is complete, the dark moon is seen covering the complete solar disk. Only the sun’s brilliant white outer atmosphere is visible. Total solar eclipses are visible only to people in the dark part of the moon’s shadow known as the umbra. A partial eclipse is seen by those in the light portion of the shadow, known as the penumbra.

Partial solar eclipses are more common in the polar regions. In this zone, the penumbra covers the dark umbra of the moon’s shadow, just missing Earth. A total solar eclipse is a rare event at any location. The next one that will be visible from the United States will take place on August 21, 2017.

**SECTION 22.2 Assessment Sun Earth Moon**

**Reviewing Concepts**

(1)In what ways does Earth move?

(2)What phenomena result from Earth’s rotation? Revolution?

(3)What causes the phases of the moon?

(4)How does the crescent phase that precedes the new moon differ from the crescent phase that follows the new moon?

(5)Why don’t eclipses occur during every full-moon or new-moon phase?

(6)Describe the locations of the sun, moon, and Earth during a solar eclipse and during a lunar eclipse.

**Critical Thinking**

(7) **Predicting** Currently, Earth is closest to the sun in January (perihelion) and farthest from the sun in July (aphelion). However, 13,000 years from now, precession will cause perihelion to occur in July and aphelion to occur in January. Assuming no other changes, how might this affect average summer temperatures for your location? What about average winter temperatures?

**SECTION 22.2 Assessment Sun Earth Moon**

**Reviewing Concepts**

(1)In what ways does Earth move?

(2)What phenomena result from Earth’s rotation? Revolution?

(3)What causes the phases of the moon?

(4)How does the crescent phase that precedes the new moon differ from the crescent phase that follows the new moon?

(5)Why don’t eclipses occur during every full-moon or new-moon phase?

(6)Describe the locations of the sun, moon, and Earth during a solar eclipse and during a lunar eclipse.

**Critical Thinking**

(7) **Predicting** Currently, Earth is closest to the sun in January (perihelion) and farthest from the sun in July (aphelion). However, 13,000 years from now, precession will cause perihelion to occur in July and aphelion to occur in January. Assuming no other changes, how might this affect average summer temperatures for your location? What about average winter temperatures?